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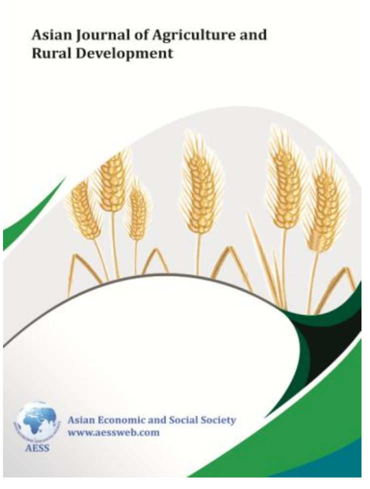

Assessment of Irrigation Land Suitability and Development of Map for the Fogera Catchment Using GIS, South Gondar

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Assessment of Irrigation Land Suitability and Development of Map for the Fogera Catchment Using GIS, South Gondar

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Abstract

Irrigation land suitability assessment and mapping play an imperative role for sustainable utilization of scarce physical land resources. The objectives of this study were to prepare spatial data base of physical land resources for irrigated agriculture and to assess land suitability for irrigation and developing suitable area map for the study area. The study was conducted at Fogera catchment, South Gondar. Soil and water sampling spots were selected based on free and grid survey techniques and their locations were taken using Global Positioning System (GPS). Geographical Information System (GIS) techniques were used to develop irrigation land suitability map of the study area. Attributes of parameters were collected and used for suitability assessment. Attributes used as criteria for irrigation suitability analysis were EC_e, ESP, soil depth, texture, pH, top and sub soil stoniness, water table depth, flood hazard, ground water quality (SAR and EC) and slope. Point data with their attribute were arranged and proximity analysis of Arc-GIS was made this resulted into twelve mapping units. The final irrigation suitability map of the project area was derived after overlay analysis. On the basis of stoniness, soil salinity, soil alkalinity, soil depth and groundwater quality it was concluded that 72 percent of the study area is potentially suitable for irrigation and 28 percent was classified as unsuitable (N) due to drainage limitation, flood hazard, texture and slope factors. Of the potentially suitable land, 1 percent was highly suitable (S_1), 28 percent was moderately suitable (S_2), and 43 percent is marginally suitable (S_3).

Keywords: parameters, GIS, land suitability, soil mapping unit.

Introduction

Agriculture is the basis for the economy of Ethiopia. It accounts for the employment of 90 percent of its population, over 50 percent of the country's gross domestic product (GDP) and over 90 percent of foreign exchange earnings (ECACC, 2002). Irrespective of this fact, production system is dominated by small-scale subsistence farming system largely based on low-input and low-output rain fed agriculture. As the result farm output lags behind the food requirement of the fast growing population. The high dependency on rain fed farming in the dry lands of Ethiopia and the erratic rainfall require alternative ways of improving agricultural production.

Considering the available water and land resources of the country, Ethiopia has immense potential in expanding irrigated agriculture. Despite its irrigation potential which is estimated to be about 3.7 million hectare, only about 190,000 hectare (5.3 percent of the potential) is currently under irrigation, which plays insignificant role in the country's agricultural production (Negash and Seleshi 2004). Use of land and water resources for the development of irrigation facilities could lead to substantial increase in food production in many parts of the world. Proper use of land depends on the suitability or capability of land for specific purposes (Fasina, et al, 2008). Thus, to bring food security at national as well as household level, improvement and expansion of irrigated agriculture must be seriously considered.

There is limited land and water resources based investigation of irrigation potential in Ethiopia (Negash and Seleshi, 2004). Small scale studies fell short in adequately providing basic soil information that can help to make appropriate decision on proper utilization of the land resources. The soil data used in such studies are based on the regional and basin wide soil studies, geomorphology and soil map of Ethiopia at 1:1000,000 scale (FAO, 1984a) and soil association map at 1:2000,000 scale (FAO, 1984b). Moreover, other site specific studies including the preliminary survey of soils in the study area failed to show detailed physical and chemical suitability of the land for irrigation. Previous works provide insufficient information to implement micro-watershed management in general and farm level irrigation planning in particular. Thus, the existing small scale irrigation system being carried out in the Fogera catchment have no adequate soil and land resource information. This calls for a need to conduct detailed to semi-detailed soil and land studies at farm levels for use in irrigation suitability analysis. Detailed and accurate data on the soil and land resources is the first requirement in evaluating land for irrigation suitability (Jafarzadeh et al, 2005). Land evaluation is related with the selection of suitable land, and suitable cropping, irrigation and management alternatives that are physically and financially practicable and economically viable (FAO, 1985).

The specific objectives of the study were to prepare spatial database of physical land resources for irrigated agriculture, assess land suitability area for irrigation in Fogera catchment, and to develop irrigation suitability map of the catchment using GIS tools.

Study Area

Fogera plain is a vast agricultural land located at 11050'42" N and 370 39' 45" E (Figure 1). The plain is adjacent to Lake Tana (source of Blue Nile) with an altitude of about 1800 m.a.s.l. The dominant soil type in the area is clay soil and the soils within the command area have moderately deep to deep effective soil depth. These soils have poor drainage and workability character. Some parts of the command area, specially the lower parts, are (flooded) with the rainwater in the rainy season for about 3-4 months. The temperature of the area ranges between 6.3 0C to 33 0C. The area is characterized by uni-modal rainfall pattern with annual average rainfall of 1259 mm. The land use of the selected study area is 74.76 percent cultivated, 1.74 percent grazing land, 23.06 percent forest and 0.44 percent degraded. Topography includes 76 percent plain, 13 percent gentle slope and 11 percent mountainous (Wolelaw, 2005). The sources of water for irrigation in the catchment include ground water wells on farmer's field, and a local river (Gwanta River) which has an average base flow of 263 liter/sec. Small scale irrigations are managed by local farmers. Major irrigated crops grown include onion, rice, tomato and maize.

Figure 1 Location of the study area

Data and Methods

Topographic map (1:50,000) and Aerial Photograph (1:250,000) of the study area are collected from the Ethiopian mapping agency (EMA). The project area was selected based on topography and access to irrigation water supply. General information about the study area on climate, soil and vegetation were also collected from available document. Interpretation and identification of features were made using the existing 1:250,000 and 1:50,000 scale aerial photograph and topographical maps respectively. To delineate the watershed, traverse survey was made using GPS. This data was then down loaded to a GIS environment and used to develop the boundary of study area. Digital elevation model (DEM) from the SRTM is used for topographic analysis. Soil and water sampling locations and elevations were captured as a point. These digital data sets were imported to a GIS environment.

Soil, Water, Slope Data

Based on a preliminary soil and water survey, soil samples are collected from three profile and nine auger holes. The spots are selected using both grid survey and free survey techniques. Being a medium intensity soil survey one observation per 50 ha was taken as per the recommendations of FAO (1979). Observation sites were located according to the requirements and complexity of the soil patterns and composite soil samples were used for soil analysis. Profile explorations were made at three suitable sites based on the soil color, drainage property of the specific location, source of irrigation water and relative position in the slope of the study area.

Drainage characteristics, water logging risk, internal drainage of the profile and visible soil saturated condition are determined using auger hole where the water table depth were also measured (Dennis et al., 2005). Depth and duration of flood inundation were measured on areas where water logging occurs during the cropping season. These measurements were used to assess flood hazard.

In characterizing the topsoil and subsoil, three profile and nine auger holes (sampling points) were collected at 20 cm and 80 cm depth and their geographic location recorded using hand held GPS. The samples were analyzed for texture, salinity, ESP, pH and soil stoniness.

The soil samples were first air-dried, grounded and passed through 2 mm sieve to undertake the physical and chemical analysis. The soil samples were analyzed for top soil texture, stoniness, soil salinity, pH and soil alkalinity. Texture analysis of a soil sample was made using hydrometric method as described by Gupta (2004). Stoniness was assessed by sieving. In order to assess the salinity hazard of a soil, electrical conductivity (ECe) measurements were carried out. For this, the saturation paste extract was prepared (Gupta, 2004), and ECe was determined by conductivity meter and expressed in millimose per centimeter (mmhos/cm). Soil pH was read simultaneously using pH meter from saturation paste extract. ESP was determined after analyzing sodium concentration and cations exchange capacity of the soil. Sodium concentration was determined using flame photometer; while CEC measurement was made by ammonium acetate method. The exchangeable sodium percentage was calculated, by dividing exchangeable sodium to cation exchange capacity.

Salinity of the groundwater was measured using electrical conductivity meter and the pH of the groundwater sample was measured with pH meter. Sodium adsorption ratio were determined after analyzing sodium with flame photometer, calcium and magnesium were determined using atomic absorption spectrophotometer. Sodium adsorption ratio was calculated by dividing sodium concentration to the squares root of the average of sodium and magnesium concentrations.

Water was sampled from wells, which were used at house hold irrigation water sources. High spot areas were visited from selected wells located at upper, middle and lower part of the catchment area and thereafter, water was sampled. Total study area was classified based on elevation source which helps as mapping unit for water quality assessment. The sampling took place during dry season. Two samples per month were collected during irrigation period from nine locations. Samples from wells were collected after withdrawal of water for some hours. At the time of collection, a label bearing a short identifying description was attached to the bottle. Name of the farmer, location, irrigated crops, farmers observation on the source of the irrigation water were also recorded. Topographic map (1:50,000) of the study area available from Ethiopian Mapping Agency are too sparse and hence are not suitable. Hence slope of the study area is derived from SRTM–DEM.

Spatial Data Analysis

Suitability Criteria Used

The framework followed in this land suitability evaluation study is one given by Dent and Anthony (1981) and FAO (1976). In addition, land evaluation standards for land resource mapping given by Dennis et al (2005) were also used for evaluation with little adjustments according to local conditions. As such field survey data and laboratory results were rated based on land evaluations method for irrigated agriculture. The evaluation is made on the basis of different land characteristics and their appraisal for irrigation purpose such as the soil, topographic, water quality and drainage situation as recommended by FAO.

The suitability classification was grouped at the first level of the land development units in six classes; Class I – III: suitable for irrigated agriculture, Class IV: not irrigable, except under special conditions, Class V: undetermined suitability for irrigation; and Class VI: non-irrigable. The second level of the classification is based on four factors: soil limitations, salinity, topography and drainage situation.

Separate land suitability classifications were made for the investigated land area with respect to each land use. In essence, suitability ranges were defined separately for each of the qualities and three suitability classes (S1, S2 and S3) were used within the order of suitable and one as class (N) within the order of not suitable.

Proximity Analysis

The aerial extent of measured parameters is determined using the Thiessen polygon interpolation. Hence texture, salinity, ESP, pH and soil stoniness raster maps are generated from the measured data and assigned to each mapping unit resulted from the Thiessen polygon boundaries. Proximity analysis of Arc-GIS spatial analysis generated twelve Mapping units (Figure 2).

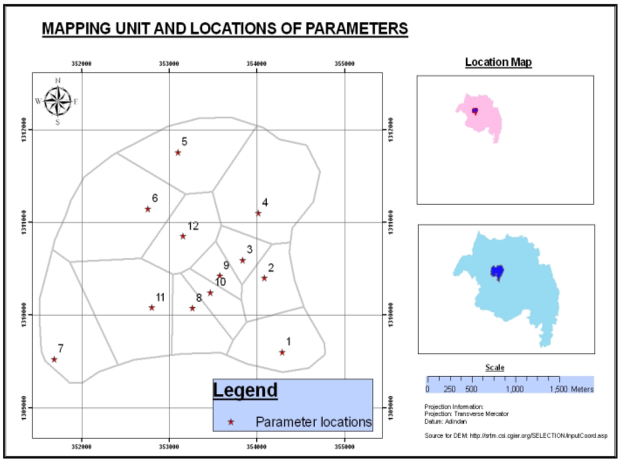

Figure 2: Mapping units developed using proximity analysis

Irrigation Land Suitability Analysis

Based on the suitability criteria assigned, layer of the criteria were developed, an overlay analysis was done to generate one suitability map which have the attribute of all land qualities with their theme attribute table. An overlay analysis in GIS was operated by Boolean operator (Burrough, 1989).

Results

Physico-Chemical Properties of Soil

Based on geographic location of sampling point taken at the study area, raster map units are generated as shown the above (Figure 1) and the parameters were distributed through the Thiessen polygons and values were extracted from study area boundary. According to different properties of soils, relative proportion of soil separates; effective soil depth, the pH, saturation extract electrical conductivity values, ESP and stoniness are presented in Table 1.

Table 1: Soil Physico-Chemical Analysis

Map unit	Soil descriptions									
	Soil depth (cm)	**Depth (cm)**	**Sand (%)**	**Silt (%)**	**Clay (%)**	**pH**	**ECe (ds/m)**	**ESP (%)**	**Stoniness (%)**	**Textural class**
1	>150	0-20 20-80	11 14	31 29	58 57	5.4 5.7	0.06 0.128	4.0 4.9	4 10	Clay Clay
2	>150	0-20 20-80	14 14	24 29	62 57	5.0 5.1	0.06 0.129	3.8 3.7	4 5	Heavy Clay Clay
3	>150	0-20 20-80	14 14	41 41	45 45	5.1 5.2	0.06 0.129	3.82 3.7	2 4	Clay Clay
4	>150	0-20 20-80	20 20	40 50	40 30	6.74 6.99	0.129 0.256	2.12 1.95	3 4	Clay Clay loam
5	>150	0-20 20-80	14 23	26 51	60 26	5.45 6.43	0.704 0.32	3.66 6.53	3 3	Clay Silty loam
6	>150	0-20 20-80	21 16	36 38	43 46	5.81 5.81	0.06 0.07	2.17 2.94	3 3	Clay Clay
7	>150	0-20 20-80	16 18	31 33	53 49	7.29 6.82	0.128 0.128	2.04 1.69	3 4	Clay Clay
8	>150	0-20 20-80	14 14	24 41	62 45	5.0 5.3	0.06 0.128	4.34 2.63	4 13	Heavy Clay Clay
9	>150	0-20 20-80	14 14	29 29	60 60	5.0 5.6	0.38 0.32	3.1 5.8	2 3	Clay Clay

10	>150	0-20 20-80	16 17	24 25	60 58	5.5 5.8	0.704 0.256	4.0 6.01	2 3	Clay Clay
11	>150	0-20 20-80	16 17	31 30	53 53	5.4 6.4	0.128 0.129	4.0 4.3	2 3	Clay Clay
12	>150	0-20 20-80	17 17	25 25	58 58	5.1 5.6	0.192 0.193	2.12 2 .0	4 5	Clay Clay

Depth, Texture and Stoniness

As it was seen from auger-hole observation and profile description of soils, the soil depths at all sampling points were greater than 150 cm. Hence the soil in the study area could be considered as very deep soil. The soil texture sample was dominantly clay. It ranges from clay to heavy clay for top soil and clay to silty loam for sub-soil. The soil color was varied from dark reddish brown to reddish brown and dark reddish gray. The maximum percentage of clay in the surface soil was observed as 62 percent on mapping units 2 and 8, and the minimum percentage of clay was recorded as 26 percent in the sub-soil on mapping unit 5. In all sampling units, proportion of silt to sand ratio was generally high. In all mapping units, the ratios were greater than one and the sand proportions were below 20 percent. This might be attributed to the deposition of clay and silt particles which were flooded from uplands to outside of the study area.

No rock out crop was observed in the study area; however, there was a negligible coarse fragment. As shown in Table 2, all mapping units showed that top soil stoniness and sub-soil stoniness were less than 5 percent and 15 percent respectively. There was no significant variation of stoniness in volume percentage for all mapping units, but there was slight increase in volume percentage with regard to depth.

pH, Salinity and Sodicity

The soil pH (H2O) values were found in the ranges of 5 to 7.29. According to Dennis etal. (2005) pH classification, soil pH has shown strongly acidic to moderately acidic. The highest pH value as 7.29 was observed on mapping unit-7 and the lowest as 5.0 were recorded. Majority of mapping units have shown an increasing trend of soil pH with depth. This may be due to the higher buffering capacity attributed to the relatively higher organic matter content of the areas or it may be indicating a presence of vertical movement of exchangeable bases.

The salinity of soil measured as saturated extract ranged from 0.06 to 0.704 dS/m. The highest surface ECe reading was obtained on mapping units five and ten, which were both less than one. Due to the moderately acidic nature of the soils of the study area, the ECe values were negligible. Moreover, there was no significant difference in ECe values. This indicates that there would not be any actual and potential salinity hazard in the soils of the study area.

In terms of Na+ hazard or sodicity of the soil, ESP differed from a minimum of 1.6 percent in mapping unit-7 to a maximum of 6.53 percent in mapping unit-5. According to Charles and Gathiru (2003) soil classification as, majority of soil was found non–sodic, as carried on ESP value was less than 6 percent. Exchangeable Na were found in very low concentration in all mapping units and did not show significant variation as compared to the critical level that caused deterioration of soil structure and Na toxicity when the ESP was greater than 15 percent as indicated in Dent and Anthony (1981). Apparently, this is due to the high amount of annual rainfall at the study area which causes excessive leaching of basic cations and finally which results in soil acidity.

Chemical Properties of Irrigation Water

Table 2 shows water quality of wells measured in terms of pH, salinity and sodicity in the laboratory. The water quality characterized by pH value varied from 6.86 to 7.69. In all catchments the pH of water was neutral. However, the upper catchment (W1 and W2) showed lower pH value 6.86 and

7.08 when compared to lower catchments 7.69, 7.48 and 7.62 (W7, W8 and W9) respectively.

All electrical conductivity values measured were low; the maximum value was less than 250 µm/cm. The dominant soluble cation in the irrigation water was Ca2+. The sodium adsorption ratio was very small for all sampling point.

This low salinity water, can be used for irrigation with most crops and most of the soils with little likelihood that salinity problem will develop. The water was also non-sodic, and it could be used for irrigation on almost all soils with little danger for development of harmful levels of exchangeable sodium.

Table 2: Groundwater Quality of Kuar Catchment

Map unit	Well	Ca (meq/l)	Mg (meq/l)	Na (meq/l)	SAR	ECw	pH
Upper catchments	W1	1.44	1.2	0.36	0.31	0.21	6.86
	W2	0.96	0.96	0.17	0.17	0.16	7.08
Middle catchment	W3	0.96	0.48	0.22	0.26	0.14	7.69
	W4	0.96	1.2	0.17	0.16	0.16	7.13
	W5	2.16	0.72	0.17	0.14	0.18	7.14
	W6	1.44	0.72	0.23	0.22	0.23	6.89
Lower catchments	W7	1.2	1.44	0.39	0.34	0.19	7.69
	W8	0.48	1.2	0.14	0.15	0.09	7.48
	W9	0.72	0.72	0.14	0.16	0.08	7.62

Flood Hazard and Drainage Investigation

Field investigation also showed a moderate flood hazard for majority of mapping units on the basis of flood depth measurements with duration and information from soil landscape or geomorphic/landform. Result obtained from field measurements, it is evident that less than 25 cm depth of flood appeared less than month flood duration for all mapping units except mapping units 2, 3 and 4 which did not have any flood risk because of their elevation as result the flood limitation was considered slight.

On close observation of internal site drainage potential from a profile, soil with auger hole and wells depth of water table were measured for drainage criteria. Mapping units 2, 3, 4, 6, 9, 10, 11 and 12 had a depth in the range of 150-200 cm. This showed a slight limitation of drainage hazard. However, the rest of mapping units were having moderate limitation since it had a range of 100-120 cm water table depth for mapping units-1, 5, 7, and 8. This might be as a result of heavy textured soil and relatively flat topography of the study area.

Rating of Land Mapping Unit

Land evaluations ratings based on the description results in the table below are shown in Table 3 All mapping units were rated as class one (I) for effective soil depth, top soil stoniness, sub soil stoniness, soil salinity, soil alkalinity, water salinity and sodicity for all catchments (upper, middle and lower). In addition, the texture of the soil was found to be under Class II for all mapping unit except mapping unit-2 and 8, as they fell in Class I.

The water table depth rating was found to be Class II for mapping units-2, 3, 4, 6, 9, 10, 11 and 12 while the others fell in class III. Moreover, flood hazards for all mapping unit were found to be Class II except mapping units-2, 3 and 4 which were found in class I.

Table 3: Land Evaluation Classes

		Suitability Class for Land Qualities						
Map units	Soil depth (cm)	Effective Soil depth	Texture	Stoniness	Salinity	Alkalinity	Flood hazard	Water table depth
1	0-20	I	II	I	I	I	II	III
	20-80			I	I	I		
2	0-20	I	I	I	I	I	I	II
	20-80			I	I	I		
3	0-20	I	II	I	I	I	I	II
	20-80			I	I	I		
4	0-20	I	II	I	I	I	I	II
	20-80			I	I	I		
5	0-20	I	II	I	I	I	II	III
	20-80			I	I	I		
6	0-20	I	II	I	I	I	II	II
	20-80			I	I	I		
7	0-20	I	II	I	I	I	II	III
	20-80			I	I	I		
8	0-20	I	I	I	I	I	II	III
	20-80			I	I	I		
9	0-20	I	II	I	I	I	II	II
	20-80			I	I	I		
10	0-20	I	II	I	I	I	II	II
	20-80			I	I	I		
11	0-20	I	II	I	I	I	II	II
	20-80			I	I	I		
12	0-20	I	II	I	I	I	II	II
	20-80			I	I	I		

Overall Evaluation

The final objective of the study was to develop irrigation land suitability map of the study area. To reach on one final irrigation suitable map, a cartographic model for each suitability criteria was developed. Based on this cartographic model, an overlay analysis was done and one overall irrigation suitable map was developed. Irrigation suitable map was derived by overlaying all parameter maps. The total area was found to be highly suitable with regard to stoniness, soil salinity, soil alkalinity, soil depth, water electrical conductivity and water alkalinity.

The spatial suitability assessment for irrigation based on overlaid maps of parameters shows that about 72 percent of the study area were potentially suitable for irrigation. Of the potential suitable land, one percent was highly suitable, 28 percent was moderately suitable, and 43 percent was marginally suitable as shown in Figure 3.

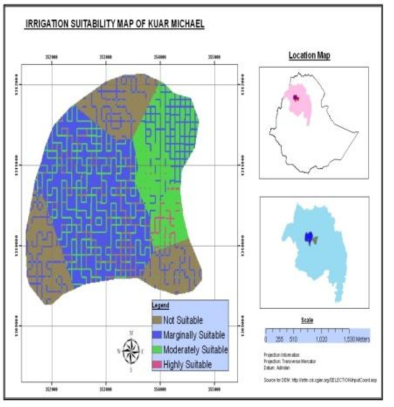

Figure 3: Overall Irrigation Suitability Map of the Study Area

Based on area delineated, percentage and area coverage were determined. From texture map, 11 percent (76.7 ha) and 89 percent (625.5 ha) were found to be heavy clay and clay which implies highly suitable and moderately suitable, respectively. Water table depth map shows that 120-150 cm depth were found 35 percent (244.86 ha) area coverage whereas water table depth of 150-200 cm were found 65 percent (457.43ha). From flood hazard map had resulted into 76.7 percent (538.65 ha) and 23.3 percent (163.64 ha) moderately suitable and high suitable respectively.

On the DEM different types of colors were observed. The area with the same color means that those areas have the same surface elevation. The abrupt change of color indicates that there was a difference in elevation within short distance. From the DEM using GIS command (surface) the surface slope of the area was developed. This surface slope then grouped and a slope category was developed. The surface slope was categorized into six slope range, viz, zero to five percent, 5 to 10 percent, 10 to 15 percent, 15 to 20 percent, 20 to 25 percent, and >25 percent and this slope categories had an area of 606.54 ha, 53 ha, 17.52 ha, 6.59 ha, 0.000081 ha and 12.9 ha, respectively. Based on FAO suitability classification for surface irrigation, slopes were reclassified in the range of 0-2 percent, 2-5 percent, 5-8 percent, and >8 percent and the corresponding areas were found to be 107.34 ha, 499.2 ha, 9.63 ha and 86.12 ha respectively.

Discussion

Sound information on soils, water and other land characteristics provide a basis for decision making on proper utilization and management of natural resources. The importance of land evaluation points to opportunities for influencing future developments of soils in the region using management techniques that are tailored to the characteristics of the landscape elements.

The total area was found highly suitable with regard to stoniness, soil salinity, soil alkalinity, soil depth, water electrical conductivity and water alkalinity. Mapping units-2, 3 and 4 were suitable with regard to flood hazard. All mapping units had limitations with regard to drainage limitation and flood hazards.

Conclusion

The land resource data, that have been generated, could be integrated through GIS techniques for effective irrigation planning in catchments. Most of the study area is suitable for irrigation (72 percent of the total area) and future irrigation development is feasible. The project area is especially suitable with respect to soil depth, soil salinity, soil alkalinity, stoniness and ground water quality which was class one (S1). Based on the finding of this study, it was clear that the main limiting factor for irrigation suitability in the area is drainage limitation for mapping units.

By a way of recommendation, in order to sustainably develop the area for irrigation development, the following points should be considered.

- Due to shallow water table depth and fine textured soil of the study area, the area has poor drainage and workability problems under excessive moisture regimes. These soils could be made more suitable by adopting improved drainage system, soil and crop management practices. Hence an appropriate drainage provision should be taken into consideration in further development.
- For the area which have slope above 8%, land leveling operation or soil conservation work have to be incorporated to break surface slope and to make it suitable for surface irrigation.
- In order to protect the flooding of lower catchment, watershed management activities including the construction of flood protection ditches on eastern boundary of the study area is recommended.
- Local interpolation for constructing Thiessen polygon had edge effect. To fully cover the surface of an interpolated area, some unknown points around the edges of the dataset would have to be extrapolated to exactly delineate the mapping units.
- The slope generated from SRTM-DEM does not represent the exact slope derivatives for the study area since it had low resolution. Precision could be improved if high resolution DEM is generated. Future work should take into consideration in using finer resolution image data.
- The validity of the spatial analysis depends on the database. Had more criteria and constraints, which affect irrigation suitability would have been considered in the analysis, the prediction would be more valid. The layers as indicated in the text were generated based on few factors.

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